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CHAPTER 2

USE OF DISTILLERS CO-PRODUCTS IN DIETS FED TO BEEF CATTLE

Terry J. Klopfenstein, Galen E. Erickson, and Virgil R. Bremer

Consumers in the United States purchase 64 pounds of beef per year. That beef is considered “high quality” by international standards. In the distant past in the United States, beef was produced with forages, and it still is in most countries of the world today. Beef cattle are ruminants and therefore are able to convert grasses, hays, and crop residues into tasty, nutritious meat. Even today in the United States, about 80% to 90% of the feed required to produce “grain-fed” beef is forage. The U.S. beef produced today is “high quality” because the cattle are fed corn just prior to harvest. How did feeding corn to cattle develop and what are the consequences of much of that corn being converted to fuel ethanol and its associated by-products?

Historical Increase in Corn Production

In 1935, 82 million acres of corn were harvested in the United States, mostly by hand. The average yield was 24.2 bushels per acre, so the total production was 2 billion bushels. Farms were small, labor requirements were high, and most farms had several livestock species, including some cattle. The national cow herd was about 10 million, and American per capita beef consumption was 51 pounds. From 1935 to 1945 the United States was engaged in a world war, which dramatically increased food demand. At the same time, hybrid seed corn was being produced and sold commercially, and Haber-Bosch technology was being used to produce nitrogen fertilizer for corn. By 1950, corn acres had declined but yields had increased to 38.2 bushels per acre, and total production had increased to 2.6 billion bushels.

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Because of the war effort to produce corn, as well as technological developments, corn production exceeded demand. In 1956, the U.S. government addressed the “farm problem” of too much corn, by encouraging farmers to “soil-bank” cropland, paying them not to produce corn. The same farmers realized that it was profitable, in most cases, to feed the cheap corn to cattle—marketing the corn through the cattle. Feeding the corn to beef cattle produced the high-quality beef to which U.S. consumers have since become accustomed. By 1950, the cow herd increased to 16.7 million, and beef consumption increased to 64 pounds per person.

Until 2006, the farm problem was too much corn. The cheap corn further encouraged cattle feeding, with segmentation of the cattle feeding into feedlots, separating it from farming. For example, about 3.3 million cattle were fed for harvest (finished) in 1965 in Iowa. Only 3.9% of the cattle were produced in feedlots of 1,000-head capacity or larger. By 1980, about 2.7 million cattle were finished in Iowa, and 37.6% were finished in feedlots of 1,000-head capacity. Over the same period, the number of cattle finished yearly in Texas increased from 1.1 million in 1965 to 4.2 million in 1980, with 98.7% in feedlots over 1,000-head capacity. In 2006, 93.9% of Nebraska cattle were fed in feedlots over 1,000-head capacity, and 38.4%, in feedlots over 16,000-head capacity. This growth in cattle feeding was supported primarily by cheap corn. Americans are currently consuming 64 pounds per person of high-quality (i.e., corn-fed) beef.

Corn production has continued to increase so that yield was 149 bushels per acre and total production was 267 million tons (10.5 billion bushels) in 2006. Because of technological advances, corn production has increased by nearly 2 bushels per acre each year since 1960. With the growth of the ethanol industry, the demand for corn has increased. During the last half of 2006, the corn price increased from about \$2 per bushel to above \$4 per bushel. With more acres planted to corn and good yields, the price of corn in 2007 declined to a range of \$3.00 to \$3.75 per bushel. However, the price increased to \$6 per bushel in early 2008. Therefore, the cattle industry is faced with the prospect of producing cattle under the constraints of high corn prices after sixty years of “cheap corn.” And the farm problem has changed from too much corn to a debate about food versus fuel.

Protein Supplements for Feedlot Cattle

The nutrition of cattle has been well researched, and advances have increased production efficiency and reduced costs of production. Research determined that cattle needed supplemental protein to complement the energy in grains and lower-protein forages. Several by-products were used for this purpose: soybean meal, cottonseed meal, tankage, and distillers grains from the beverage alcohol industry. With the development of the Haber-Bosch process for producing ammonia, it became commercially feasible to produce urea. It was determined that urea could be used as a protein substitute for ruminants. Protein supplements cost cattle feeders 2 to 2.5 times the price of corn. This is the reason urea was used widely—it supplied protein (nitrogen) less expensively than did protein supplements such as soybean meal. Beef cattle nutritionists formulated diets as economically as possible and generally believed that energy was cheap and protein was expensive.

With the use of corn for production of ethanol, the resulting by-product, distillers grains, became readily available for cattle feeders. When corn is used to produce ethanol, the starch in the corn is fermented into ethanol, and the distillers grains are the unfermented materials remaining—fiber, protein, and fat. Corn is about two-thirds starch, so when starch is removed (fermented), the remaining nutrients are concentrated in the distillers grains by a factor of three. Corn has about 10% protein while distillers grains contain about 30%. Therefore, corn, primarily a source of energy (starch), is converted into a protein source. With more corn used for ethanol, more distillers grains are produced. Because of supply and demand, the distillers grains are generally not more expensive than corn. Therefore, producers have turned to distillers grains as an energy source for feed. This is a major paradigm shift for cattle nutritionists and cattle feeders. Protein is no longer more expensive than energy. In fact, because energy in corn is being used for fuel, the large supply of energy for livestock has decreased and has been replaced by a large supply of protein.

Cereal grains have been fermented to produce beverage alcohol for centuries. By the late nineteenth century, the resulting by-product, distillers dried grains with solubles (DDGS), was being used as a feedstuff (Henry, 1900). Morrison (1939) and Garrigus and Good (1942) refer to a liquid

form of the by-product supplied to beef cattle as “distillers slop.” Individuals involved in the beverage distilling industry formed the Distillers Feed Research Council in 1945 to “expand the, then, meager knowledge available on the nutrient composition of distillers feeds and to better understand how these feeds would be best used in a variety of livestock feeding systems.” The Distillers Feed Research Council was replaced in 1997 with the Distillers Grains Technology Council (Louisville, KY). Both of these organizations have held annual conferences, and the proceedings contain a wealth of information about the traditional uses of DDGS.

Stock et al. (2000) described the dry milling process whereby grain, mainly corn, is fermented to produce ethanol. Again, about two-thirds of corn is starch, which is the component that is fermented into ethanol in the dry milling process. The remaining nutrients are recovered in the stillage, and water is removed to produce DDGS. Protein increases from about 10% to 30%, fat from 4% to 12%, neutral detergent fiber (NDF) from 10% to 30%, and phosphorus from 0.3% to 0.9% of dry matter.

Because of the increased concentration of protein in the DDGS compared to corn, the DDGS were used primarily as a protein source (Klopfenstein et al., 1978). Aines, Klopfenstein, and Stock (1987) reviewed reports on rumen protein escape values of DDGS and found them to be variable, likely because of the measurement technique. Average protein escape values for DDGS were 2.6 times greater than those for soybean meal, and values for dry distillers grains minus solubles were 2.3 times greater than those for soybean meal. Klopfenstein et al. (1978) used the slope ratio technique in growth studies to determine protein values relative to soybean meal. Aines, Klopfenstein, and Stock summarized several experiments showing 2.4 times the value of distillers dried grains protein compared to that from soybean meal, and DDGS had 1.8 times the value of soybean meal. DeHaan et al. (1982) observed that distillers solubles had 0.45 times the escape protein of soybean protein. One might expect that the protein in distillers solubles would be completely rumen degradable, especially when distillers solubles are produced by centrifugation, which would remove most grain particles. However, much of the protein in distillers solubles is composed of yeast cells, which have been heated during distillation and concentration. In their experiment, Bruning and Yokoyama (1988) showed that heat denatured the yeast cells, rendering them resis-

tant to lysis and microbial degradation. Herold (1999) showed only 20% protein degradation in the rumen of wet milled distillers solubles, which contained mostly yeast cells. Therefore, some escape of protein in distillers solubles from dry milling should be expected.

In addition to protein, NDF is concentrated in DDGS compared to corn and comprises most of the carbohydrate in distillers grains with solubles (DGS). Quicke et al. (1959) found high in vitro digestion of cellulose in corn fiber. DeHaan, Klopfenstein, and Stock (1983) demonstrated that corn bran (corn grain pericarp) is primarily NDF (69%) and that the NDF has a high extent (87%) and rate (6.2%/h) of digestion. Sayer (2004) reported similar extents of corn bran NDF digestion (79% to 84%) in situ in fistulated cattle fed finishing diets. Rates of digestion of NDF in these finishing diets were less (1.7% to 2.1%/h) than those reported by DeHaan, Klopfenstein, and Stock, likely because of relatively low ruminal pH in the finishing diets.

Distillers Grains in Feedlot Diets

Wet Distillers Grains with Solubles

Perhaps the first study designed to include DGS as an energy source was conducted by Farlin (1981). He fed wet distillers grains without solubles, replacing 25%, 50%, and 75% of the corn in a finishing diet. Even though the perceived energy nutrient (starch) in corn had been removed, the resulting by-product actually had more energy per pound than the corn it replaced. Firkins, Berger, and Fahey (1985) and Trenkle (1996, 1997, 2008) found similar results with wet distillers grains with solubles (WDGS).

Larson et al. (1993) conducted a series of experiments designed to evaluate WDGS fed as a protein source or as an energy source. The hypothesis was that locating an ethanol plant adjacent to a feedlot would allow feeding of the product wet, eliminating the necessity of drying the by-product. The WDGS were fed at 5.2% and 12.6% of diet dry matter to supply metabolizable protein or crude protein needs, and at 40% of the diet (dry matter basis) to supply protein and replace corn in the diet as an energy source. At the 40% level, feed efficiency of the diet was increased 14% compared to the corn control (Table 2.1). Assuming the increase in efficiency was due to WDGS, the WDGS had 35% greater feeding value than corn.

Table 2.1. Calf performance when fed different dietary inclusions of wet distillers grains with solubles for protein and energy

Item	WDGS level, % of diet dry matter ^a				P-value	
	0	5.2	12.6	40.0	SE	Linear Quadratic
Dry matter intake, lb/day	18.57	19.27	18.61	17.44	0.29	< 0.01 0.21
Average daily gain, lb	2.87	3.06	3.09	3.22	0.07	< 0.01 0.13
Gain/feed ^b	0.155	0.158	0.164	0.177	0.003	<0. 01 0.54
Hot carcass wt, lb	714	734	741	754	7	0.01 0.15
Fat thickness, in	0.51	0.55	0.55	0.55	0.04	0.21 0.27
Marbling score ^c	497	530	530	580	20	0.01 0.51

Source: Adapted from Larson et al., 1993.

^aWet grains:thin stillage = 1.67:1, dry matter basis.

^bAccounts for ethanol consumption.

^cWhen 400 = Slight⁰ and 500 = Small⁰.

Vander Pol et al. (2006) fed 0%, 10%, 20%, 30%, 40%, and 50% WDGS as a replacement for corn. They found quadratic responses to average daily gain (ADG) and feed efficiency and a cubic response in feeding value according to the WDGS level (Table 2.2). Feed efficiency at all levels of WDGS inclusion was better than the 0% WDGS corn control diet.

Nine experiments conducted in the same feedlot under relatively similar conditions were used for a meta-analysis (Klopfenstein, Erickson, and Bremer, 2008). Levels of WDGS replacing dry-rolled corn, high-moisture corn, or replacing a combination of the two ranged from 5.2% to 50%. The most common levels were 30% and 40%, and there was only one comparison at 50%. Experiments had 10 (individually fed) to 50 steers per treatment, and most had more than 40 steers per treatment. The nine experiments included 34 treatment means representing 1,257 steers.

There were quadratic responses to ADG and dry matter intake (DMI) (Table 2.3), with ADG and DMI being maximized at about 30% WDGS. The quadratic relationship for ADG from feeding WDGS is $y = -0.0005x^2 + 0.028x + 3.47$, where $y =$ ADG in lb and $x =$ percent inclusion in the diet on a dry basis. Therefore, the maximum ADG is achieved at an inclusion of 27.9% of the diet based on these nine experiments. The feed efficiency of the diet was maximized at 30% to 50% of diet, and the relationship tended to be quadratic ($P < 0.09$). The equation for a quadratic response for feed efficiency from feeding WDGS is $y = -0.00000093x^2 + 0.000847x + 0.156$, where $y =$ feed efficiency and $x =$ percent inclusion in the diet on a dry basis. Therefore, feed efficiency is maximized at 45.6% inclusion of WDGS on a dry matter basis. Feeding values were calculated from the feed efficiency values and show decreasing feeding value as the level of WDGS in the diet increased. The feed efficiency values did not decrease for the diets at the high inclusion levels but, because of accounting for inclusion level in the diet, the feeding values decreased with inclusion level. Because the cattle gained more rapidly when fed WDGS compared to corn, they were fatter with equal days on feed. Consistent with the quadratic increase in rib fat was a quadratic increase in quality grade.

Distillers Dried Grains with Solubles

Drying of distillers grains is expensive because of the cost of fuel and the capital investment in equipment. Fuel ethanol is an energy source designed

Table 2.2. Cattle performance when fed different dietary inclusions of wet distillers grains with soluble to finishing yearling steers

WDGS Inclusion:^a	CON	10WDGS	20WDGS	30WDGS	40WDGS	50WDGS	SEM	Lin^b	Quad^c	Cubic^d
Dry matter intake, lb/day	24.03	24.70	25.14	26.02	24.48	23.37	0.31	0.09	< 0.01	0.81
Average daily gain, lb	3.66	4.08	4.12	4.32	4.28	3.92	0.09	0.01	< 0.01	0.45
Gain/feed ^e	0.153	0.165	0.164	0.173	0.176	0.169	0.002	< 0.01	< 0.01	0.43
Feeding value, % ^f	100	178	138	144	137	121	7	0.81	< 0.01	< 0.01
Hot carcass wt, lb	778	803	809	829	827	798	8.2	< 0.01	< 0.01	0.18
12 th Rib fat, in	0.45	0.54	0.49	0.52	0.46	0.50	0.03	0.80	0.08	0.01
Longissimus muscle area, in ^a	12.35	12.77	12.82	12.51	12.38	12.35	0.19	0.36	0.09	0.13
Marbling score ^g	515	538	520	523	501	505	11.6	0.11	0.29	0.22

Source: Adapted from Vander Pol et al., 2006.

^aDietary treatment levels (dry matter basis) of WDGS, CON = 0% WDGS, 10WDGS = 10% WDGS, 20WDGS = 20% WDGS, 30WDGS = 30% WDGS, 40WDGS = 40% WDGS, 50WDGS = 50% WDGS.

^bContrast for the linear effect of treatment P-value.

^cContrast for the quadratic effect of treatment P-value.

^dContrast for the cubic effect of treatment P-value.

^eCalculated as total gain over total DMI.

^fCalculated from feed efficiency relative to control, divided by WDGS inclusion.

^g400 = Slight⁰, 500 = Small⁰.

Table 2.3. Wet distillers grains plus solubles meta-analysis predicted cattle performance and carcass characteristics

	WDGS level (% of diet dry matter)						t-statistic	
	0	10	20	30	40	50	Linear	Quadratic
Dry matter intake, lb/day	22.31	22.73	22.78	22.49	21.83	20.82	0.01	0.01
Average daily gain, lb	3.46	3.70	3.84	3.88	3.81	3.66	< 0.01	< 0.01
Gain/feed	0.155	0.162	0.168	0.172	0.174	0.175	< 0.01	0.09
Feeding value, % ^a	100	145	142	137	131	126		
Fat thickness, in	0.49	0.52	0.54	0.54	0.52	0.49	< 0.01	0.04
Yield grade	2.85	2.95	3.02	3.04	3.01	2.94	< 0.01	0.06
Marbling score ^b	518	528	533	532	526	514	0.05	0.05

Source: The dataset included treatment means from Buckner et al., 2006; Corrigan et al., 2007; Al-Suwaigh et al., 2002; Ham et al., 1994; Larson et al., 1993; Luebke et al., 2008; and Vander Pol et al., 2006, 2008b.

^aValue relative to corn, calculated by difference of feed efficiency, divided by by-product inclusion.

^b500 = Small^o.

to replace fossil fuel (CAST, 2006). Thus, use of fossil fuel for drying is counterproductive. While many feedlot cattle are located in close proximity to dry milling plants, many are too far from plants to allow transportation of the WDGS to feedlots. In those cases, it may be logical and economical to produce DDGS to facilitate transportation.

Ham et al. (1994) compared feeding values of DDGS to WDGS in feedlot diets. The DGS were included at 40% of diet dry matter to replace corn. The WDGS were produced in a separate plant from the DDGS. The DDGS were from 11 sources and were combined into composites based on the content of acid detergent insoluble nitrogen. Cattle fed both WDGS and DDGS were more efficient than the control, corn-fed cattle (Table 2.4). Cattle fed WDGS were more efficient than cattle fed DDGS. The amount of acid detergent insoluble nitrogen did not affect feed efficiency. WDGS contained 47% higher feeding value than corn and DDGS contained 24% higher value.

Buckner et al. (2008b) conducted a feedlot study comparing 10%, 20%, 30%, and 40% levels of DDGS to a corn control. A trend for a quadratic response was observed for feed efficiency (Table 2.5). The quadratic response in gain-feed was similar to that found for WDGS by Vander Pol et al. (2006), but the feed efficiency response was somewhat less, and optimal inclusion was 20% of diet dry matter. These data were combined with four other experiments in a meta-analysis (Klopfenstein, Erickson,

Table 2.4. Effect of wet distillers grains with solubles or distillers dried grains with solubles on finishing cattle performance

Item	By-product and ADIN level ^a					SEM
	Control	WDGS	DDGS			
			Low ^a	Medium ^a	High ^a	
Average daily gain, lb ^{b,c}	3.22	3.73	3.66	3.70	3.77	0.26
Dry matter intake, lb/day ^{d,e}	24.23	23.55	25.31	25.05	25.86	1.21
Gain/feed ^{b,c,e}	0.133	0.158	0.144	0.148	0.145	0.004

Source: Adapted from Ham et al., 1994; all diets contained 40% distillers grains.

^aADIN = acid detergent insoluble nitrogen.

^bControl vs. WDGS ($P < .05$).

^cControl vs. average of DDGS composites ($P < 0.05$).

^dControl vs. average of DDGS composites ($P < 0.10$).

^eWDGS vs. average of DDGS composites ($P < 0.05$).

Table 2.5. Cattle performance when fed increasing levels of distillers dried grains with solubles to finishing steers^a

Parameter	0DDGS	10DDGS	20DDGS	30DDGS	40DDGS	SEM	P-value	
							Lin ^b	Quad ^c
Dry matter intake, lb/day	20.40	20.88	20.99	21.41	20.88	0.37	0.23	0.30
Average daily gain, lb	3.31	3.55	3.70	3.57	3.51	0.11	0.26	0.05
Gain/feed ^d	0.162	0.171	0.177	0.168	0.168	0.005	0.61	0.14
Feeding value ^e	100	156	146	112	109			
Hot carcass wt, lb	774	798	816	803	792	12	0.32	0.04
12 th Rib fat, in	0.56	0.54	0.59	0.55	0.58	0.03	0.48	0.99
Longissimus muscle area, in ^a	12.40	12.49	12.80	12.60	12.60	0.20	0.42	0.37
Marbling score ^f	533	537	559	527	525	12.7	0.50	0.18

Source: Adapted from Buckner et al., 2008b.

^aDDGS= 0% DDGS, 10DDGS = 10% DDGS, 20DDGS = 20% DDGS, 30DDGS = 30% DDGS, 40DDGS = 40% DDGS.

^bContrast for the linear effect of treatment P-value.

^cContrast for the quadratic effect of treatment P-value.

^dCalculated as total gain over total DMI.

^eValue relative to corn, calculated by difference of feed efficiency, divided by by-product inclusion.

^f400 = Slight⁰, 500 = Small⁰.

and Bremer, 2008). The meta-analysis showed a quadratic response in ADG and a cubic response in feed efficiency as the level of DDGS in the diet increased from 0% to 40% (Table 2.6). Maximum ADG was at 25.7% DDGS and maximum feed efficiency was between 10% and 20% DDGS. Compared to the meta-analysis for WDGS, the inclusion level for maximum response in feed efficiency was lower for DDGS than for WDGS; however, the inclusions to maximize ADG were similar. In addition, the feeding value of DDGS declined from the 20% inclusion level (123%) to the 40% inclusion level (100%). In contrast, the feeding value of WDGS at the 20% inclusion level was 142% and it declined to only 131% at the 40% inclusion level. There appears to be an interaction between DDGS and WDGS in feeding values at different levels of inclusion. At the 20% level of inclusion, the two types of distillers grains differed in feeding values by 19 percentage units but differed by about 31 percentage units at the 40% level of dietary inclusion. The biological basis for the interaction of distillers grains processing method and feeding value is not understood.

Modified Wet Distillers Grains with Solubles

Some ethanol plants are producing a partially dried wet distillers feed called modified wet distillers grains with solubles (MWDGS). The wet grains are partially dried, which increases dry matter content from about 35% to 42%–48%. The advantages of MWDGS relative to WDGS are the ability to add all of the solubles to the wet grains and lower transportation cost. However, there is the added cost of the partial drying. Because DDGS have lower feeding value than WDGS, the effect of “partial” drying to produce MWDGS was studied (Huls et al., 2008). MWDGS were fed at 0% to 50% of diet dry matter, replacing dry-rolled and high-moisture corn. Cattle ADG responded quadratically to increasing the level of MWDGS, with the greatest gains at the 20% inclusion level (Table 2.7). Feeding values decreased from 123% of corn at 10% inclusion to 109% at 50% inclusion.

A direct comparison of MWDGS to conventional WDGS has not been made. However, the data of Huls et al. (2008) suggest the feeding value of MWDGS is less than that of WDGS. In two studies, Trenkle (2007, 2008) also found generally lower feeding values for MWDGS than previously observed with WDGS. These observations all suggest that partial drying of MWDGS causes the feeding value to fall somewhere between those of DDGS and WDGS.

Table 2.6. Distillers dried grains with solubles meta-analysis predicted cattle performance and carcass characteristics

	DDGS level (% of diet dry matter)					t-statistic		
	0	10	20	30	40	Linear	Quadratic	Cubic
Daily feed, lb/day	22.42	22.93	23.22	23.28	23.13	0.01	0.08	0.68
Daily gain, lb	3.44	3.64	3.73	3.75	3.66	<0.01	<0.01	0.54
Gain/feed	0.152	0.160	0.159	0.155	0.152	0.07	0.02	<0.01
Feeding value, % ^a	100	153	123	107	100			
Yield grade	2.87	2.91	2.94	2.98	3.01	0.04	0.51	0.90
Marbling score ^b	540	535	529	524	518	0.07	0.13	0.79

Source: Data set included treatment mean observations from Buckner et al., 2008b; Bremer et al., 2006; Benson et al., 2005; Ham et al., 1994; and May et al., 2007a.

^aValue relative to corn, calculated by difference of feed efficiency, divided by by-product inclusion.

^b500 = Small⁹.

Table 2.7. Calf-fed steer finishing feedlot performance when fed varying levels of modified wet distillers grains with solubles^a

	CON	10MDG	20MDG	30MDG	40MDG	50MDG	SEM	Lin ^b	Quad ^c
Performance									
Initial body weight, lb	748	749	748	745	747	748	27	0.32	0.32
Final body weight ^d lb	1395	1411	1448	1439	1418	1398	38	0.82	<0.01
Dry matter intake, lb/day	23.0	23.1	23.5	23.2	22.8	21.6	0.7	0.03	0.01
Average daily gain, lb	3.67	3.75	3.97	3.94	3.81	3.69	0.10	0.73	<0.01
Gain/feed ^e	0.161	0.164	0.169	0.170	0.168	0.172		<0.01	0.28
Carcass characteristics									
Hot carcass weight, lb	879	889	912	906	893	881	24	0.82	<0.01
Marbling score ^f	520	513	538	498	505	490	17	0.10	0.42
12 th Rib fat, in	0.57	0.57	0.61	0.62	0.57	0.54	0.04	0.54	0.12
Longissimus muscle area, in ^b	12.8	12.5	12.8	12.8	12.7	12.7	0.2	0.98	0.97
Calculated yield grades ^g	3.68	3.91	3.92	3.91	3.84	3.64	0.17	0.69	0.04

^aDietary treatment levels (dry matter basis) of MWDGS, CON= 0% MWDGS, 10MDG= 10% MWDGS, 20MDG= 20% MWDGS, 30MDG= 30% MWDGS, 40MDG= 40% MWDGS, 50MDG=50% MWDGS.

^bContrast for the linear effect of treatment P-value.

^cContrast for the quadratic effect of treatment P-value.

^dCalculated from hot carcass weight, adjusted to a 63% yield.

^eCalculated from total gain over total DMI.

^f50 = Slight 50, 500 = Small 0.

^gWhere yield grade = 2.5 + 2.5(fat thickness, in) - 0.32(LM area, in²) + 0.2(KPH fat, %) + 0.0038(hot carcass weight, lb).

Metabolism and Digestion of Distillers Grains

It is a paradox that both DDGS and WDGS appear to have greater feeding values than corn and yet are less digestible because of the NDF in the distillers grains. Lodge et al. (1997b) attempted to determine the reason for this apparent paradox. They developed a “composite” distillers grains with composition as similar as possible to DDGS. The ingredients in the composite were wet corn gluten feed (corn bran and steep liquor), corn gluten meal, and tallow. The feeding value of the composite when fed at 40% of diet dry matter was 124% of the corn it replaced (Table 2.8). This feeding value is comparable to the meta-analysis of WDGS described previously. When either corn gluten meal or tallow were removed, feed efficiency decreased a similar amount numerically, indicating that both the escape protein in the corn gluten meal and the tallow were equally responsible for the high feeding value of the composite. It is unlikely but possible that the corn gluten meal met a metabolizable protein deficiency. The response is more likely from the greater energetic efficiency of undegradable intake protein compared to degraded protein or carbohydrates. Certainly the higher energy value of lipid for ruminants (Zinn, 1989) explains the response to tallow. Larson et al. (1993) estimated that the undegraded protein and fat in WDGS would increase the feeding value by about 20% compared to that of corn. This is less than the value of 30% in the meta-analysis and does not account for the lower digestibility of NDF in WDGS compared to the digestibility of starch in corn. Therefore, the paradox remains unexplained.

Metabolism of the lipid in distillers grains is important from an energetic as well as a meat composition standpoint. Vander Pol et al. (2008b)

Table 2.8. Effect of wet grains composite on finishing steer performance

Item	Treatment ^a					SEM
	DRC	WCGF	COMP2	-FAT	-CGM	
Dry matter intake, lb/day	21.50 ^b	20.90 ^{bc}	19.96 ^c	20.02 ^c	20.79 ^{bc}	1.19
Average daily gain, lb	2.93	2.87	2.98	2.91	2.93	0.29
Gain/feed	0.136 ^b	0.136 ^b	0.149 ^c	0.146 ^{bc}	0.146 ^{bc}	0.023

Source: Adapted from Lodge et al., 1997b.

^aWCGF = wet corn gluten feed; COMP2 = wet corn gluten feed, corn gluten meal, and tallow; -FAT = composite minus tallow; -CGTM = composite minus corn gluten meal.

^{b, c}Means within a row with unlike superscripts differ ($P < .10$).

conducted a feedlot study and a metabolism study to elucidate the role of lipid in distillers grains. Adding 5% corn oil to the corn control diet reduced feed efficiency by 10%. Conversely, adding a similar amount of lipid from WDGS increased feed efficiency by 8%. Fat added as corn oil was 70% digested while fat added in WDGS was 81% digested. Fatty acid profiles were measured in duodenal contents (Table 2.9). Unsaturated fatty acids were higher (30.9% of total fat) in duodenal contents of steers fed WDGS than in steers fed similar amounts of corn oil (10.8% of total fat). This suggests that some of the oil in WDGS was protected from rumen hydrolysis/hydrogenation. Plascencia et al. (2003) showed that fat digestion decreases with hydrogenation. Therefore, these data (Vander Pol et al., 2008b) are consistent by showing reduced hydrogenation and increased digestibility of the lipid in WDGS compared to those qualities of free corn oil. The metabolism data are also consistent with the feeding study in which the lipid response was positive from WDGS and negative from oil. This negative influence could be due to the influence of lipid on either rumen fermentation or fat digestion. Plascencia et al. (2003) reported that intestinal fatty acid digestion decreased with the level of total fatty acid intake, regardless of saturation. That might suggest that the declining feeding value of distillers grains as inclusion levels in the diet increase is at least partially due to declining fatty acid digestion.

Carcass Characteristics and Meat

In the meta-analysis of Klopfenstein, Erickson, and Bremer (2008), cattle fed WDGS gained more rapidly than the corn-fed cattle. More rapid gains resulted in greater fat levels because the cattle were fed the same number

Table 2.9. Fatty acid profiles of duodenal fat content of steers fed wet distillers grains with solubles or supplemental corn oil

Item	Treatment ^a		
	WDGS	CON	CON + OIL
Fatty acids ^b			
16 and 18 C unsaturated	30.9	20.1	18.4
14 to 18 C saturated	64.0	71.7	75.3
Other	5.1	8.2	6.3
Unsaturated:saturated	0.48	0.28	0.24

Source: Adapted from Vander Pol et al., 2008b.
^aWDGS = wet distillers grains plus soluble (WDGS) diet, CON = average of control diet and composite diet, CON + OIL = average of control + corn oil diet and composite + corn oil diet.
^bExpressed as proportion of fat reaching the duodenum.

of days. Marbling scores followed a similar pattern to that of ADG and fatness. In all three measurements, there was a quadratic response to the level of WDGS. Maximum ADG, fatness, and marbling were reached at about 30% of diet dry matter. Gain, fatness, and marbling were less at 50% of diet dry matter compared to 30% inclusion but not different from the corn control diet. Results were generally similar for the meta-analysis with DDGS feeding except the optimum was at a lower level of dietary DDGS inclusion. May et al. (2007a,b), Gordon et al. (2002a), and Sims et al. (2008) found similar results with steam-flaked corn diets, in that the degree of fattening and marbling paralleled that of ADG.

Gordon et al. (2002b) fed (153 d) increasing levels of DDGS with steam-flaked corn and evaluated steaks from the finished cattle. They found subtle positive differences in steak tenderness with increasing levels of DDGS as reported by a trained panel, but the researchers concluded that consumers would likely not detect differences. Steaks were displayed for seven days, and while redness decreased with time of display, there was no effect of level of DDGS feeding. Flavors were not affected by the level of DDGS feeding, and there was also no evidence of off-flavors or lipid oxidation, even at 75% DDGS in the diet.

Roeber, Gill, and DiCostanzo (2005) evaluated steaks from Holstein steers fed distillers grains at levels up to 40% and 50% in two experiments. Feeding distillers grains up to 50% of diet dry matter did not affect tenderness or sensory traits. However, the researchers noted a tendency for high levels of distillers grains feeding to have a negative effect on color during retail display. Lancaster et al. (2007) fed distillers grains at a relatively low level (15% of dry matter) and evaluated fatty acids in the resulting meat. There was no effect of distillers grains on fatty acid composition of the triacylglycerol fraction, but polyunsaturated fatty acids (PUFA) were increased in the phospholipids fraction. Gill et al. (2008) also evaluated steaks when distillers grains were fed at 15% of the diet. They found no effects due to distillers grains feeding on sensory attributes or Warner-Bratzler shear force values. They found several small changes in proportions of PUFA.

Jenschke et al. (2007) evaluated steaks from the cattle used by Vander Pol et al. (2006) that were fed 0% to 50% WDGS. The level of WDGS did not affect off-flavor intensity. Liver-like off flavor was always numeri-

cally lower in steaks from cattle fed WDGS. Jenschke et al. (2008) showed that roughage source and type did not affect fatty acid profiles or sensory properties of meat from steers fed 30% WDGS.

The data of Vander Pol et al. (2008b) show that more unsaturated fatty acids are absorbed from the intestine. De Mello, Jenschke, and Calkins (2008b) have clearly demonstrated that unsaturated fatty acids increase in beef fat with feeding of distillers grains. However, this does not appear to influence marbling observed by USDA graders, as De Mello, Jenschke, and Calkins (2008a) found that there is no change in the relationship of intramuscular fat content and marbling score in multiple experiments in which 0%, 15%, or 30% WDGS were fed.

The increased level of PUFA in beef from cattle fed DGS is a bit of a catch-22. Beef fat has been criticized for being saturated, so the greater PUFA content with DGS feeding makes beef potentially more “healthy.” Conversely, De Mello, Jenschke, and Calkins (2008c) have shown that PUFA cause more rapid discoloration of meat in the display case. Senaratne et al. (in press) have demonstrated that feeding vitamin E with distillers grains restores the shelf life of the meat. Many factors such as time in the display case, type of packaging, and oxygen content of gas in packaging will interact with the effect of PUFA from distillers grains on shelf life of beef. It is not clear at the present time whether there is a discoloration problem or whether vitamin E feeding is necessary.

Roughage Levels and Sources

Starch is removed in the production of ethanol, so when distillers grains are included in the diet, especially at levels above 20% of dry matter, the amount of starch in the diet is decreased while fiber, protein, and fat are increased. This suggests that sub-acute acidosis should be reduced and roughage (forage) content of the diet could be reduced when distillers grains are included in diets above 20%. Acidosis control (Krehbiel et al., 1995) and reduced roughage needs (Farran et al., 2006) have been demonstrated with corn gluten feed, which has a similar amount of corn fiber to that in distillers grains. In addition to supplying NDF and reducing starch in the diet, WDGS add moisture and protein to the diet. The moisture and physical characteristics (stickiness) aid markedly in palatability and reduce separation and sorting of less palatable ingredients. The protein in WDGS

reduces the need for (value of) protein in the roughage. Therefore, less expensive, lower digestible forages may be acceptable in diets with reasonably high levels of WDGS.

A feedlot study tested the response to roughage level and source in diets containing 30% WDGS (Benton et al., 2007). Alfalfa was used as the “gold standard” roughage and was fed at 4% and 8% of diet dry matter. Cornstalks were evaluated at amounts of NDF similar to the alfalfa (3% and 6% of diet dry matter). Corn silage was included as the third roughage source. The theory was that corn silage could be harvested and stored less expensively as silage compared to harvesting corn and cornstalks separately, yet it would provide both components. The silage was also included on an equal NDF basis at 6% and 12% of diet dry matter. An all-concentrate diet (no roughage) was included as a control. There was a 2- to 3-pound increase in daily DMI due to roughage inclusion while ADG increased by 0.20 to 0.50 pound (Table 2.10). These increases in DMI and ADG are typical of those observed in studies evaluating roughage levels in diets without WDGS (Shain et al., 1999). These data suggest WDGS did not supply “roughage” even though the by-product supplied NDF. However, cornstalks were as effective as alfalfa and corn silage in diets containing WDGS in providing roughage in terms of response in DMI, ADG, and feed efficiency. This is contrary to the results of Shain et al. (1999) in which wheat straw fed on an equal NDF basis to alfalfa in dry-rolled corn diets was not as efficiently utilized as alfalfa. This suggests that the moisture and protein in WDGS do in fact supply characteristics to the diet that allow utilization of low-quality roughages that are often less expensive compared to alfalfa.

Grain Processing

All of the data discussed have evaluated distillers grains in feedlot diets based on dry-rolled corn or high-moisture corn. Vasconcelos and Galyean (2007b) put together a very insightful survey of feedlot nutritionists. They reported that 65.5% of nutritionists surveyed stated that steam flaking was the most common method of corn processing. This doesn't mean that 65% of the corn fed to feedlot cattle is steam-flaked corn, only that 65% of the nutritionists in their survey responded accordingly. Their publication was not designed to quantify the amount of steam-flaked corn fed in feedlots. The total amount of steam-flaked corn may be greater than or less than

Table 2.10. Finishing performance of cattle fed diets containing wet distillers grains with solubles with three types of roughage at low or normal neutral detergent fiber levels

	CON	LALF	LC SIL	LCSTK	NALF	NCSIL	NCSTK	SE
Dry matter intake, lb/day	22.27 ^a	24.48 ^b	24.26 ^b	24.92 ^{bc}	25.80 ^c	25.36 ^c	25.58 ^c	0.44
Average daily gain, lb	4.32 ^a	4.54 ^{ab}	4.52 ^a	4.78 ^c	4.76 ^{bc}	4.74 ^{bc}	4.81 ^c	0.11
Gain/feed	0.195	0.186	0.186	0.192	0.185	0.188	0.188	0.003

Source: Adapted from Benton et al., 2007.

Note: CON = Control, LALF = low alfalfa hay (4%), LC SIL = low corn silage (6%), LCSTK = low corn stalks (3%), NALF = normal alfalfa hay (8%), NCSIL = normal corn silage (12%), and NCSTK = normal corn stalks (6%).

^{a,b,c} Means within a row with unlike superscript differ (P < 0.05).

65%. Regardless, steam-flaked corn represents a large proportion of grain fed to feedlot cattle, especially in the Southern High Plains. Feeding dry-rolled corn, high-moisture corn, and high levels of distillers grains is more common in Corn Belt states where many ethanol plants are in production or under development.

Vander Pol et al. (2008a) fed dry-rolled, steam-flaked, and high-moisture corn with 30% WDGS to finishing cattle. From the meta-analysis, this 30% inclusion level with dry-rolled or high-moisture corn would be optimal for rate and efficiency of gain. Feed efficiency for high-moisture corn was 4% greater ($P = 0.08$) than that for dry-rolled corn (Table 2.11). With each corn at 61% of diet dry matter, the high-moisture corn has 6.5% higher feed value than dry-rolled corn, which is consistent with data for these corn products when they are fed with wet corn gluten feed (Macken et al., 2006). Scott et al. (2003) and Macken et al. (2006) suggested that steam-flaked corn has 10% to 15% higher feeding value than dry-rolled corn, the higher values when fed with wet corn gluten feed. However, Vander Pol et al. (2008a) found similar feed efficiency for cattle fed steam-flaked and dry-rolled corn when 30% WDGS was included in the diet, and ADG was significantly decreased for cattle fed steam-flaked compared to dry-rolled or high-moisture corn. Drouillard et al. (2005) also obtained less response to the combination of WDGS and steam-flaked corn than

Table 2.11. Performance and carcass characteristics of steers fed 30% wet distillers grains with solubles and corn from three different processing methods

	SFC	HMC	DRC	SEM	F-test
Dry matter intake, lb/day	20.46 ^f	21.01 ^{ef}	22.67 ^c	0.22	<0.01
Average daily gain, lb ^a	3.59 ^f	3.90 ^c	4.06 ^c	0.07	<0.01
Gain/feed ^{a,b}	0.176 ^f	0.185 ^c	0.179 ^{ef}	0.002	<0.01
Fecal starch, % ^c	4.2 ^f	8.7 ^c	12.0 ^c	1.3	<0.01
Hot carcass wt, lb	822 ^f	853 ^c	871 ^c	7	<0.01
12 th Rib fat, in	0.51 ^f	0.58 ^c	0.62 ^c	0.02	<0.01
Longissimus muscle area, in ^b	12.60	13.19	13.00	0.20	0.16
Marbling score ^d	496 ^f	544 ^c	540 ^c	10	<0.01

Source: Adapted from Vander Pol et al., 2008a.

^aCalculated from adjusted final body weight.

^bCalculated as total feed intake (dry matter basis) divided by total gain.

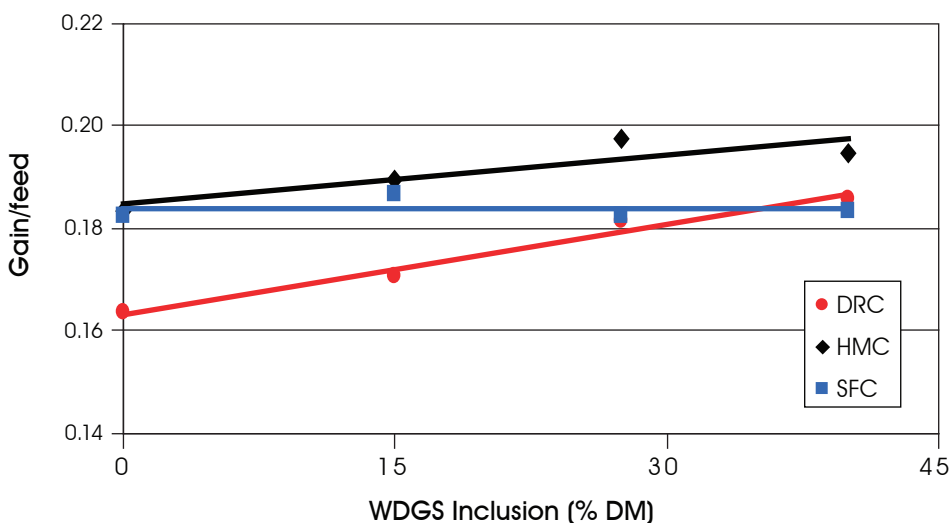
^cPercentage of fecal dry matter.

^dWhere 400 = Slight⁰, 500 = Small⁰.

^{e,f,g,h}Means within a row with unlike superscripts differ ($P < 0.05$).

expected and suggested the optimal level of WDGS was less than the 30% level used by Vander Pol et al. (2008a).

Corrigan et al. (2007) evaluated the interaction between level of WDGS inclusion and grain processing method. WDGS were fed at 0%, 15%, 27.5%, and 40% rates of dry matter in diets consisting of dry-rolled, high-moisture, or steam-flaked corn (3x4 factorial design). Interactions for ADG and feed efficiency were observed between level of WDGS and grain processing type (Figure 2.1). At 0% WDGS, the steam-flaked corn had 14% greater feeding value than that of dry-rolled corn, which is consistent with Cooper et al. (2002) and Owens et al. (1997). When WDGS were added to dry-rolled corn, there was a linear increase ($P < 0.01$) in feed efficiency such that at 40% inclusion, efficiency was similar to that of the steam-flaked corn diets. When WDGS was added to the steam-flaked corn diets, there was no change in feed efficiency. The feeding value for WDGS in steam-flaked corn diets appears to be equal to that of steam-flaked corn, which was 14% greater than that of dry-rolled corn in this



Source: Adapted from Corrigan et al., 2007.

Figure 2.1. Feed efficiency of finishing steers fed differing levels of wet distillers grains with solubles (WDGS) with dry-rolled corn (DRC), high-moisture corn (HMC), or steam-flaked corn (SFC). Linear effect of WDGS level with DRC ($P < 0.01$), linear effect of WDGS level with HMC ($P < 0.05$), and corn processing method by WDGS level interaction ($P < 0.01$)

trial. However, WDGS had a 34% higher feeding value than dry-rolled corn averaged across levels in this trial. The high-moisture corn diet with 0% WDGS gave feed efficiency values similar to those of the steam-flaked corn diet without WDGS. However, addition of WDGS to high-moisture corn gave a linear ($P < 0.05$) improvement in feed efficiency. While this experiment clearly showed the interaction between WDGS level and grain type on cattle performance, it certainly did not explain possible mechanisms. The relatively poor response to WDGS in steam-flaked corn diets has also been shown by May et al. (2007b).

Feeding Value of Sorghum Distillers Grains

While corn is the primary grain used for ethanol production, grain sorghum has been and continues to be used as a feedstock. The grains have similar amounts of starch and therefore have similar ethanol yields. Sorghum is usually less expensive than corn so it is an attractive feedstock for ethanol plants. Lodge et al. (1997a) suggested that sorghum distillers grains had less feeding value than corn distillers grains. However, their comparison was somewhat indirect. Al-Suwaiegh et al. (2002) made a direct comparison of sorghum and corn distillers grains from the same ethanol plant. The two distillers grains were fed at 30% of the diet with dry-rolled corn. Although feed efficiency was not significantly different, it favored corn distillers grains by 3%, giving the WDGS from corn a 10% higher feeding value compared to WDGS from sorghum. Two additional experiments have been reported in which sorghum distillers grains were compared to corn distillers grains in steam-flaked corn diets. Levels of DGS fed were lower than those reported by Al-Suwaiegh et al. (2002) so the distillers grains were used primarily as a protein source. In addition, the two types of distillers grains were produced by different ethanol plants. Vasconcelos et al. (2007c) reported statistically similar responses for sorghum and corn distillers grains (0.169 vs. 0.176 gain-feed), but the feeding value of the corn distillers grains was 40% greater than that of the sorghum distillers grains. Depenbusch et al. (2005) did not show a significant difference between sorghum and corn distillers grains (0.148 vs. 0.153 gain-feed), but the feeding value of corn distillers grains was 25% greater than that of sorghum distillers grains. Considering the four experiments reported, one might conclude that sorghum distillers grains are equal to corn distillers grains based on non-significant differences. However, the corn distillers grains were superior numerically in all experiments, so it is risky to conclude the two are equivalent in feeding value.

Combinations of By-products

With the large-scale expansion of ethanol plants in the Midwest, an option for many feedlots will be to utilize both WDGS and wet corn gluten feed concurrently. In addition to their commercial availability, another reason for feeding a combination of WDGS and wet corn gluten feed is their nutritional profiles. Complementary effects in feeding a combination of these by-products might be expected because of differences in fat, effective fiber, and protein components. Loza et al. (2005) fed yearling steers a 50:50 blend of WDGS and wet corn gluten feed (dry matter basis) at inclusion levels of 0%, 25%, 50%, and 75% of diet dry matter. All inclusion levels of the blend were evaluated with 7.5% alfalfa hay in the diets. Additional treatments were also evaluated using a lower alfalfa level with each of the by-product diets. Therefore, forage inclusion decreased as the rate of inclusion of by-products in the diets increased (i.e., 25% blend had 5% alfalfa in the lower forage treatment, 50% blend had 2.5% alfalfa, and 75% blend had 0% alfalfa). Results indicated that there were no differences in cattle performance between forage levels for each by-product's blend level. The lack of differences in performance with decreasing forage would indicate that the inclusion of the by-products was enough to prevent the negative consequences of sub-acute acidosis (Table 2.12). The analysis of the pooled data from each co-product level indicated that the performance of the steers fed the maximum by-product level (75%), regardless of the forage level, was not different from a typical corn-based diet (0% co-products blend). However, the diets including a 25% and 50% blend of WDGS and wet corn gluten feed resulted in significantly better animal performances than the control diet.

Table 2.12. Effect of different inclusion levels of a 50:50 blend of wet distillers grains with solubles and wet corn gluten feed and forage levels fed to yearling steers

Blend:	0%	25%		50%		75%	
Alfalfa:	7.5	5.0	7.5	2.5	7.5	0.0	7.5
Dry matter intake, lb/day	24.30 ^a	26.30 ^{bc}	26.50 ^b	25.40 ^c	26.10 ^{bc}	23.00 ^d	23.60 ^{ad}
Average daily gain, lb	3.99 ^a	4.70 ^b	4.57 ^b	4.55 ^b	4.56 ^b	3.86 ^a	3.93 ^a
Gain/feed	0.164 ^a	0.179 ^c	0.172 ^{bc}	0.179 ^c	0.175 ^{bc}	0.168 ^{ab}	0.166 ^{ab}

Source: Adapted from Loza et al., 2005.
a,b,c,d Means with different superscripts differ (P<0.05).

Buckner et al. (2006) fed the same combination of WDGS and wet corn gluten feed at 30% or 60% dietary dry matter compared to feeding the by-products alone at 30% dietary dry matter or a 0% by-product diet. The 30% WDGS diet gave the best performance. However, feeding wet corn gluten feed or WDGS in a blend (1:1 dry matter basis) or alone improved performance over cattle fed a corn-based diet (0% by-product). A second trial by Loza et al. (2007) compared a 0% by-product diet to six other diets containing a constant amount of wet corn gluten feed (30% diet dry matter) and additions of WDGS at 0%, 10%, 15%, 20%, 25%, or 30% diet dry matter. Including WDGS at 15% to 20% of the diet with 30% wet corn gluten feed had the greatest ADG. This research agrees with Buckner et al. (2006) in that the 30% wet corn gluten feed plus 30% WDGS gave better performance than the corn-based control diet. These three studies demonstrate that high levels of by-products, when used in combination, can be fed to feedlot cattle without reducing performance compared to corn-based control diets. Vasconcelos and Galyean (2007a) found a combination of 20% wet corn gluten feed and 7% DDGS worked well in a steam-flaked corn diet.

Feeding a combination of WDGS and wet corn gluten feed can also serve as a management tool. A major challenge facing some ethanol plants is not having by-products available for cattle feeders on a consistent basis. Cattle do not respond well if either WDGS or wet corn gluten feed, as a sole by-product in the diet, is removed and replaced with corn abruptly. Therefore, one approach would be to feed a combination to ensure that at least one by-product is consistently in the ration.

Sulfur

Buckner et al. (2008c) took 1,200 samples of WDGS from six ethanol plants over a ten-month period. The average sulfur content was 0.78%. However, there was some variation among samples, with one sample at 1.72%. Corn contains 0.14% to 0.16% sulfur. This suggests that distillers grains would have about 0.45% of the sulfur that is in the corn. The sulfur from the corn is primarily in the form of sulfur amino acids, and it may be only 40% degraded in the rumen. The remaining sulfur is from sulfuric acid and sulfamic acid used for pH control and cleaning of distillation columns. The sulfur is reduced in the rumen to H_2S , which is absorbed. The H_2S may directly or indirectly cause polioencephalomalacia (PEM)

(Gould, 1998). The PEM condition is referred to among feedlot personnel as “brainers” because the cattle experience neurological problems.

The National Research Council (1996) suggests the upper limit for sulfur in the diet is 0.4% of dry matter. That level is based on very little data. More recently, the National Research Council (2005) suggested that beef cattle fed forage-based diets could tolerate 0.5% sulfur, and cattle fed concentrate (less than 40% forage) could tolerate 0.3% sulfur (dry matter basis). Over the past several years, numerous experiments have been conducted at the University of Nebraska in which various levels of by-products have been fed, providing numerous, and sometimes high, levels of sulfur. Data were summarized on 4,143 cattle finished in experiments involving by-products. There were 23 animals diagnosed by the feedlot health crew as being “brainers” (PEM suspects). Some responded to thiamine therapy. (All diets contained 75 to 150 mg/day thiamine.) Those that died were necropsied and diagnosed as PEM. We assume that all 23 were suffering from PEM, but the survivors were not diagnosed clinically, which requires inspection for brain lesions.

Eleven of the 24 “brainers” were on one dietary treatment. The diet had 0.47% sulfur and no roughage. It is presumed that the lack of roughage was a predisposing factor in the development of the 11 PEM cases. These cases are excluded from the following analysis.

In diets with less than 20% by-product, sulfur levels were relatively low, and 0.1% of the cattle were diagnosed with PEM. We assume this is a normal baseline level of PEM and includes cattle on diets with no by-products. In diets with greater than 20% by-products and less than 0.46% sulfur, 0.14% of the cattle were diagnosed with PEM. This appears to be similar to the baseline level. Between 0.46% and 0.58% levels of sulfur, 0.38% of the cattle were diagnosed with PEM, and above 0.58% sulfur, 6.06% were diagnosed with PEM.

We conclude that the risk of PEM is low when diet sulfur levels are below 0.46%. Above 0.46% sulfur, the risk increases quite dramatically. A diet with 50% of the dry matter as WDGS is about 0.47% sulfur if the WDGS has 0.72% sulfur. Knowing the sulfur level of the by-product is very important if high levels of by-products are being fed. Water can be

an additional source of sulfur and should be checked before high levels of by-products are fed (DeWitt et al., 2008).

Feeding Distillers Grains and *E. coli* Shedding

There were only eight recalls due to *E. coli* O157:H7 in ground beef in 2006, and all of them were initiated because of company sampling. However, in 2007 there were 20 recalls, and nine of those recalls resulted from illness investigation. Health officials looked for reasons why *E. coli* O157:H7 (referred to simply as *E. coli* hereafter) seemed to be a greater problem in 2007 compared to the previous four years. Because the ethanol industry grew in 2007 and feeding ethanol by-products increased, some theorized feeding ethanol by-products was the cause of the *E. coli* recalls. Late in 2007, research (Jacob et al., 2008b) showing a relationship between distillers grains feeding and *E. coli* shedding was reported.

Jacob et al. (2008c) reported a study using 370 feedlot cattle sampled at 122 and 136 days on feed. Prevalence overall was fairly low (under 10%). On day 122, cattle were statistically more likely to shed *E. coli* when fed 25% distillers grains in the diet. On day 136, there was no effect on shedding from feeding distillers grains. Jacob et al. (2008b) sampled cattle for twelve weeks during the feeding period. Fecal samples were collected from the pen floor. Feeding distillers grains significantly increased *E. coli* shedding, although there was no difference in 5 of the 12 sampling periods.

Jacob et al. (2008d) conducted a challenge experiment in which calves were inoculated with nalidixic-acid-resistant *E. coli*, allowing researchers to estimate the number of the *E. coli* shed. Fecal samples were collected for forty-two days. *E. coli* shedding was not different for calves fed distillers grains during the first five weeks but was statistically greater during the last week of sampling. Based on these three studies, researchers concluded that feeding distillers grains increased *E. coli* shedding. In each of the three experiments there were sampling times when distillers grains statistically increased shedding; however, as with most results in *E. coli* research, the results were somewhat inconsistent, making interpretation of the results somewhat difficult.

Recently, Jacob et al. (2008a) reported results of an experiment using 700 cattle fed for 150 days, and with half being fed distillers grains. Pen floor samples were collected weekly or every two weeks, and a total of

3,560 samples were collected and analyzed. Overall prevalence of *E. coli* was fairly low (5.1%). Although prevalence in pen floor fecal samples was numerically higher on some sampling weeks in cattle fed distillers grains, there was no significant effect ($P = 0.2$).

All of the previous studies were conducted with steam-flaked corn diets with or without 25% distillers grains (dry matter basis). This may be important as we compare other research projects and results. Corrigan et al. (2007) have reported that distillers grains do not respond the same in steam-flaked corn diets compared to dry-rolled or high-moisture corn diets. If cattle gains and efficiencies respond differently to distillers grains levels in steam-flaked, dry-rolled, or high-moisture corn diets, then it is possible that any effects on *E. coli* vary as well. Our *E. coli* research is with dry-rolled or high-moisture corn only.

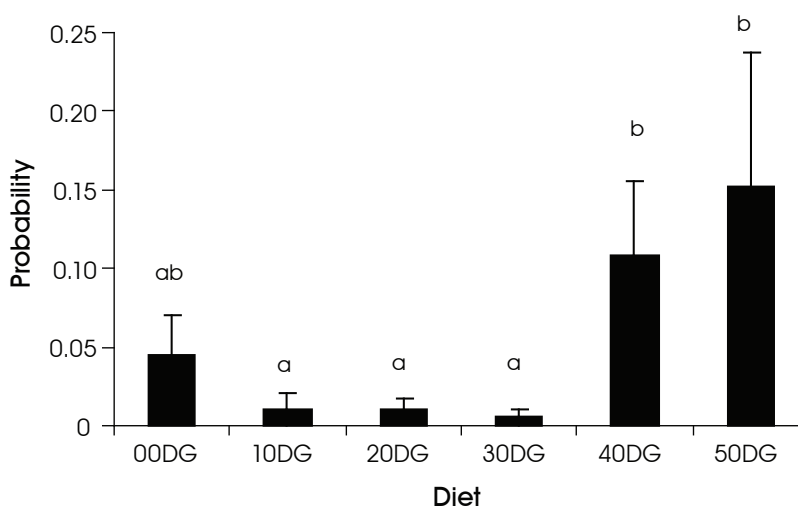
It is logical that the diet fed to cattle could influence the growth of *E. coli* in the hindgut. Research has shown that the primary reservoir of *E. coli* is the hindgut and that the *E. coli* attach to the intestinal wall of the hindgut. Interestingly, the *E. coli* have no effect on cattle performance. There are two opposing theories on how the diet affects *E. coli* in the hindgut. The first theory is that starch escaping digestion in the rumen and small intestine is fermented in the hindgut, producing volatile fatty acids and lowering pH—inhibiting growth of the *E. coli*. Fox et al. (2007) showed support for this theory: steam flaking reduced starch in the hindgut and increased *E. coli* shedding. However, Depenbusch et al. (2008) said “*E. coli* O157:H7 was not related to fecal pH or starch.” We reanalyzed the data of Peterson et al. (2007a), in which diets with decreasing amounts of corn were fed—decreasing the amount of starch in the diet. The amount of starch in the diet was not related to *E. coli* shedding ($P = .22$).

The opposing theory is that starch in the hindgut is the substrate for *E. coli*, so by reducing the amount of starch getting to the hindgut, *E. coli* would be reduced. Reports of Peterson et al. (2007a) and Folmer et al. (2003) did not support this theory. While it is logical that diet affects *E. coli* growth in the hindgut, clearly neither of the two opposing starch theories has been proven.

Peterson et al. (2007b) focused on vaccination as an *E. coli* intervention. Because the study was superimposed on a nutrition study, we reanalyzed

the data (Figure 2.1). Wet distillers grains were fed as 0%, 10%, 20%, 30%, 40% and 50% of diet dry matter replacing dry-rolled and high-moisture corn. In this experiment, samples of the hindgut mucosa were analyzed, as were fecal samples. Results were similar but more consistent for the mucosal samples (Figure 2.2). There was a significant effect of level of distillers grains on *E. coli* shedding; however, it was not a linear relationship. None of the levels of distillers grains feeding was statistically different from the control (no distillers grains). The 10%, 20%, and 30% distillers grains levels numerically decreased the shedding of *E. coli*. Interestingly, this is within the range of feeding (25%) discussed previously with steam-flaked corn. Our research is with dry-rolled and high-moisture corn while the previous research was with steam-flaked corn, which may make a difference.

At the 40% and 50% distillers grains feeding levels, *E. coli* shedding numerically increased compared to the control. Note that the statistical difference is between the 10%, 20%, and 30% distillers grains levels and the 40% and 50% levels. So does feeding distillers grains decrease or increase *E. coli* shedding?



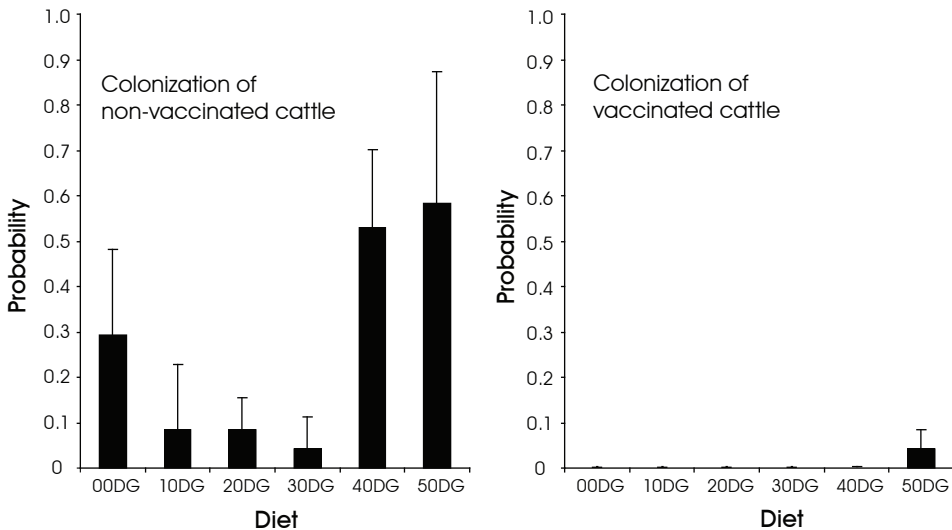
Source: Adapted from Peterson et al., 2007b.

a,b,c Treatment means with unlike letters differ.

Figure 2.2. Effect of level of wet distillers grains with solubles (WDGS) on *E. coli* O157:H7 colonization by cattle, 00DG = corn control diet with no WDGS, 10DG = 10% WDGS, 20DG = 20% WDGS, 30DG = 30% WDGS, 40DG = 40% WDGS, 50DG = 50% WDGS

In the Peterson et al. (2007b) study with *E. coli* vaccination, the pattern of *E. coli* in hindgut mucosa for unvaccinated cattle was similar to that discussed previously (Figure 2.3). However, there was only one steer that tested positive among the vaccinated cattle and that was one fed distillers grains at the 50% level. In four studies involving 1,784 cattle, vaccination reduced *E. coli* shedding by 65%. This is equivalent to the effect of winter versus summer on shedding. Feeding a direct-fed microbial (Peterson et al., 2007a) reduced shedding over two years by 35%. These two interventions plus others being researched have considerable merit.

The data on the effect of distillers grains on *E. coli* O157:H7 shedding are inconclusive at best. The compiled data do not indicate that distillers grains feeding significantly affects *E. coli* shedding. Studying *E. coli* O157:H7 requires many observations and substantial resources. Focusing future research on the development and implementation of these interventions will be the most beneficial way to improve pre-harvest food safety.



Source: Adapted from Peterson et al., 2007b, J. Food Prot. 70: 2568-2577.

Figure 2.3. Effect of level of wet distillers grains with solubles (WDGS) on *E. coli* O157:H7 colonization of unvaccinated or vaccinated against *E. coli* O157:H7. 00DG = corn control diet with no WDGS, 10DG = 10% WDGS, 20DG = 20% WDGS, 30DG = 30% WDGS, 40DG = 40% WDGS, 50DG = 50% WDGS

Use of Distillers Grains in Forage-Fed Cattle

Beef calves (from weaning until they enter feedlots), developing heifers, and beef cows are fed primarily forage diets. Forages are low in protein and phosphorus, especially in the winter. Stocker calves, developing heifers, and cows on low-quality forage need supplemental phosphorus and protein. Cows may also need energy supplementation. It is advantageous if the same commodity can be used for supplemental energy as well as for protein and any phosphorus that may be needed. By-product feeds can be used to meet these requirements of cattle in pasture and range situations. An additional advantage for distillers grains is that these feeds contain very little starch and therefore should not depress fiber digestion as corn does in some situations.

Animal Performance

An experiment was conducted with 120 crossbred heifers to determine the value of DDGS in high-forage diets and to evaluate the effect of supplementing daily compared to three times weekly (Loy et al., 2008). Heifers were supplied with ad libitum access to grass hay and supplemented with DDGS or dry-rolled corn. Supplements were fed at two levels and offered either daily or three times per week in equal proportions. Heifers supplemented daily ate more hay, gained faster (1.37 vs. 1.24 lb per day), but were not more efficient than those supplemented on alternate days (Table 2.13). At both levels of supplementation, heifers fed DDGS gained more and were more efficient than heifers fed dry-rolled corn. The calculated feeding values for DDGS were 30% and 18% greater than for dry-rolled corn when fed at 10% and 34% of diet dry matter.

Ten ruminally cannulated heifers received no supplement, DDGS daily, DDGS on alternating days, dry-rolled corn daily, or dry-rolled corn on alternating days (Loy et al., 2007). Hay intake was higher for non-supplemented than for supplemented heifers (Table 2.14). No intake differences were observed between DDGS and dry-rolled corn supplemented heifers. Heifers supplemented daily had higher and more consistent intakes than those in alternate-day treatments, particularly within corn-supplemented heifers. Ruminal pH and hay fiber disappearance were greater in non-supplemented heifers. Corn-supplemented heifers had slower rates of fiber digestion than DDGS-supplemented heifers.

Table 2.13. Growing calf performance over eighty-four days when fed native grass hay (CP = 8.7%) supplemented with either corn or distillers dried grains with solubles for two levels of gain

		Low ^a	High ^b
Average		0.81 ± 0.06	1.57 ± 0.05
daily gain, lb/d	Corn		
	DDGS	0.99 ± 0.05	1.89 ± 0.05
Gain/feed	Corn	0.063 ± 0.007	0.102 ± 0.007
	DDGS	0.078 ± 0.007	0.125 ± 0.007

Source: Adapted from Loy et al., 2008.

^aLow = supplement fed at 0.21% BW, about 10% of diet, DDGS 130% feeding value of corn.

^bHigh = supplement fed at 0.81% BW, about 34% of diet, DDGS 118% feeding value of corn.

Table 2.14. Treatment effects on intake, neutral detergent fiber disappearance, ruminal pH, and intake pattern

Item	CON	DRC-D	DRC-A	DDGS-D	DDGS-A
Hay dry matter intake, % of body weight ^{a,b}	1.88	1.69	1.58	1.69	1.66
Total dry matter, % of body weight ^{a,b}	1.88	2.10	1.98	2.09	2.06
NDF disappearance, %/hour ^{a,c}	4.34	3.43	3.65	4.09	4.01
Average ruminal pH ^{a,c}	6.30	6.22	6.22	6.12	6.19
Meals per day ^{b,d}	5.9	6.6	4.0	6.0	5.1

Source: Adapted from Loy et al., 2007.

Note: CON = no supplement; DRC-D = dry rolled corn supplement fed at 0.46% of body weight daily; DRC-A = DRC at 0.92% of body weight on alternate days; DDGS-D = DDGS supplement fed at 0.45% of body weight daily; DDGS-A = DDGS at 0.90% of body weight on alternate days.

^aCON vs. supplemented treatments, $P < 0.05$.

^bSupplementation frequency effect, $P < 0.10$.

^cDDGS vs. DRC, $P < 0.05$.

^dSupplement x frequency interaction, $P < 0.08$.

Dry distillers grains contain approximately 65% undegradable intake protein (% of crude protein); consequently, forage-based diets that include DDGS fed as an energy source are commonly deficient in degradable intake protein but contain excess metabolizable protein. Cattle convert excess metabolizable protein to urea, which is potentially recycled to the rumen and can serve as a source of degradable intake protein. Many factors influence urea recycling, and the amount of urea that is recycled when DDGS are included in a forage-based diet is not known.

Two experiments evaluated requirements for supplemental degradable intake protein when feeding DDGS as an energy source in forage-based diets (Stalker, Adams, and Klopfenstein, 2007). Diets were formulated to be deficient by more than 100 grams per day in degradable intake protein but to have excess metabolizable protein. No response in performance was observed when urea was added to the diet (Table 2.15). Sufficient urea was probably recycled to correct the degradable intake protein deficiency. These studies indicate adding urea to meet the degradable intake protein requirement is not necessary when feeding DDGS as an energy source in forage-based diets.

Given recent drought conditions in many areas of the United States and the price of pasture and hay, these by-products may be very competitive as energy supplements for use by ranchers. When forage quality is poor (winter) or quantity is limited (drought), by-products may provide opportunities for producers to maintain or improve forage and cattle productivity.

Table 2.15. Performance of animals fed diets in which 0%, 33%, 67%, 100%, or 133% of the National Research Council predicted degradable intake protein requirement was met with supplemental urea

Item	Diet					F-Test	
	0	33	67	100	133	SEM	P-Value
Individually fed							
Initial body weight, lb	611	611	615	617	614	11	0.99
Final body weight, lb	694	697	680	702	702	15	0.85
Average daily gain, lb	1.06	1.03	0.93	1.01	1.04	0.07	0.77
Total dry matter intake, lb/day	11.3	11.4	11.4	11.5	11.4	0.2	0.95
Gain/feed	0.090	0.085	0.076	0.085	0.085	0.007	0.54
Pen fed							
Initial body weight, lb	452			449		1	0.10
Final body weight, lb	579			585		4	0.38
Average daily gain, lb	1.53			1.63		0.05	0.17
Total dry mater intake, lb/day	11.9			11.6		0.5	0.76
Gain/feed	0.102			0.110		0.004	0.33

Source: Adapted from Stalker, Adams, and Klopfenstein, 2007.

A meta-analysis of grazing trials in which cattle were supplemented DDGS was conducted to determine the effects of DDGS supplementation on ADG and final body weight in pasture grazing situations (Griffin et al., in press). Additionally, pen studies were evaluated to determine the effect of DDGS supplementation on cattle intake, forage replacement, ADG, and final body weight. Treatment means were compiled from trials in which cattle were allowed to graze pasture and supplemented DDGS ($n = 35$) and for trials in which cattle were pen-fed a forage-based growing ration and supplemented DDGS ($n = 28$). Supplementation of DDGS ranged from 0 to 8 pounds per animal daily with an average supplementation of 2.8 pounds per animal daily. Studies in which cattle were pen-fed and supplemented DDGS used 348 cattle that were fed either hay or a forage mix containing 60% sorghum silage and 40% alfalfa hay. The mix was used to simulate the diet that cattle would consume if grazing high-quality forage.

Supplementing DDGS to cattle grazing pasture increased final body weight and ADG (Figure 2.4) with increased supplementation. Supplementing DDGS in growing rations consistently increased final body weight and ADG quadratically (Figure 2.4; $P < 0.01$) as the level of DDGS supplementation increased. Total intake increased quadratically (Table 2.16; $P < 0.01$) as the level of DDGS supplementation increased. As DDGS supplementation increased, forage intake decreased quadratically. Cattle grazing pasture and consuming similar levels of DDGS had lower ADG compared to pen-fed cattle. Since DDGS supplementation was at the same level for both pasture- and pen-fed cattle, this leaves forage intake as the variable input. Forage replacement could have been greater in pasture-fed animals compared to the pen-fed studies, leading to an overall decrease in intake in the pasture studies compared to the pen studies. In both pasture and pen studies, forage quality was similar. Therefore, the amount of forage replaced could be a logical explanation for the increased ADG response in the pen studies compared to the pasture studies. The replacement of forage by DDGS increased as the level of DDGS supplementation increased (Table 2.16).

Heifer Development

An experiment was conducted using 1,353 heifers to evaluate the use of DDGS supplementation to reduce wintering costs in an extended-grazing heifer development system (Stalker, Adams, and Klopfenstein, 2006).

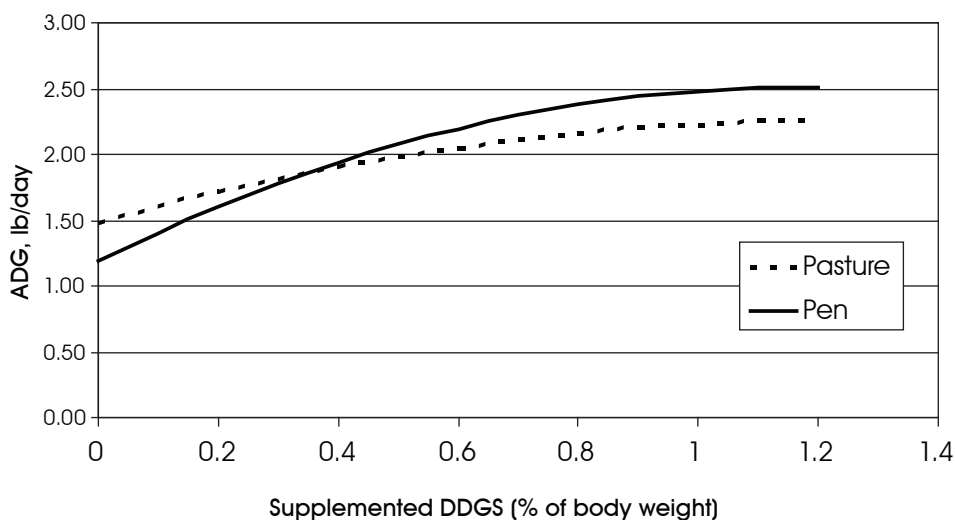


Figure 2.4. Effect of distillers dried grains with solubles supplementation on average daily gain of growing cattle. x = supplemented distillers dried grains as a percentage of steer body weight. Pasture ADG = $1.4736 + 1.2705x - 0.5156x^2$. Pen fed steer ADG = $1.1828 + 2.2703x - 0.9715x^2$

Because of the higher energy content of DDGS, a smaller amount of hay was needed to meet protein and energy requirements of DDGS-fed bred heifers. Feeding DDGS and grazing winter range led to slightly better winter gains and improved body condition compared to the hay-fed control heifers. The pregnancy rate was 97% for both treatments. Most importantly, \$10.47 per heifer was saved in feed costs by using DDGS and winter range versus a conventional system of hay, supplement, and range. A two-year study (Martin et al., 2007) evaluated DDGS compared to a control supplement that provided similar crude protein, energy, lipid, and fatty acids to developing heifers. The protein degradability of the supplements differed such that the amount of undegradable intake protein supplied by DDGS exceeded heifer requirements, and the protein supply from the control supplement did not meet heifer requirements. The heifers were program-fed to gain 1.5 pounds per day and reach 60% of mature weight at the time of breeding. Heifer pubertal development and overall pregnancy rate were not affected by supplement type and averaged 89% for each treatment. However, artificial insemination conception and pregnancy rates were improved by feeding DDGS in the heifer development diet. The proportion of heifers detected in estrus that conceived to

Table 2.16. Effect of supplemental level of distillers dried grains with solubles on intake of growing cattle

DDGS Supplementation:^a	0.0	1.5	3.0	4.5	6.0	7.5	Lin^b	Quad^b
Total intake, lb/day	12.7	13.9	14.9	15.7	16.3	16.6	< 0.01	< 0.01
Forage intake, lb/day	12.7	12.4	11.9	11.2	10.3	9.1	0.31	< 0.01
Forage replacement, ^d lb/day	0.0	0.3	0.8	1.5	2.4	3.6	---	---
Forage replaced/DDGS, ^d lb/lb	0.00	0.20	0.27	0.33	0.40	0.48	---	---

Source: Adapted from Griffin et al., in press.

^aSupplementation level of DDGS (dry matter basis) in lb/steer daily.

^bEstimation equation linear and quadratic term t-statistic for variable of interest response to DDGS supplementation level.

^cForage replacement calculated using forage intake at 0.0 lb/d supplementation and subtracting forage intake value for respective level of supplementation.

^dThe amount of forage replaced per lb of DDGS supplemented.

artificial insemination service was higher for the DDGS treatment than for the control treatment. These data indicate that utilizing DDGS as a protein and energy source in heifer-developing diets to promote moderate gains gives highly acceptable pregnancy rates and may enhance artificial insemination conception and pregnancy rates.

Corn Stalk Grazing

The last forage situation that may fit well with use of by-products is corn stalk grazing. Incremental levels of DDGS were fed to calves grazing corn residues. Based on statistical and economical analysis of the data collected, feeding DDGS (5.0–6.5 lb per steer daily, dry matter basis) will increase stocking rate on corn residue and may reduce winter cattle costs (Gustad et al., 2006). Given that feeding 3.5 pounds of DDGS dry matter will meet the protein and phosphorus needs of calves, and feeding above 6.0 pounds daily will not increase gains, DDGS should be fed at 3.5 to 6.0 pounds of dry matter per steer daily, which should produce gains of 1.4 to 1.7 pounds of ADG.

Storage of Wet Distillers Grains with Solubles

One problem that can be encountered is storage of wet feeds. Bagging of WDGS can be successful if no pressure is applied to the bagger. Bags tend to settle because of the weight of the WDGS, resulting in low height and expanded width. MWDGS (45% dry matter) and wet corn gluten feed bag well, even with pressure.

Erickson et al. (2008) conducted two experiments to determine methods to store WDGS (34% dry matter), because WDGS will not store in silo bags under pressure or pack into a bunker. The first study evaluated three forage sources, as well as DDGS or wet corn gluten feed mixed with WDGS. The products were mixed in feed trucks and placed into 9-foot diameter silo bags. The bagger was set at a constant pressure of 300 psi. The height of the silo bag was a determining factor of storability. Inclusion levels of the feedstuffs were adjusted to improve the bag shape. The recommended levels of feedstuffs for bagging with WDGS (dry matter basis) are 15% grass hay, 22.5% alfalfa hay, 12.5% wheat straw, 50% DDGS, and 60% wet corn gluten feed. The corresponding as-is percentages for the feedstuffs are 6.3%, 10.5%, 5.1%, 27.5%, and 53.7% of the mix, re-

spectively. The second experiment was conducted by mixing grass hay with WDGS and storing in a concrete bunker. Both 30% and 40% mixtures of grass hay with WDGS (dry matter basis) were packed into the bunker. These values correspond to 14.0% and 20.1% of the as-is grass hay mix. In both experiments, the product was stored for more than forty-five days, and the apparent quality did not change. Wet distillers grains can be stored in a silo bag or bunker silo when mixed with drier or bulkier feedstuffs. More information is available at <http://beef.unl.edu>.

Storage allows cattle feeders with smaller numbers of animals to use wet by-products and not have the products deteriorate with extended time between deliveries of fresh material from the plant. Wet by-products are often more available and less expensive in the summer. Storage allows for purchase of wet by-products in the summer and subsequent feeding in the winter.

Ensiled mixtures of WDGS with either wheat straw or cornstalks have been fed to stocker calves. The palatability of forages seems to have been enhanced by storage. The feeding value is at least equal to what would be expected from the mathematical blend of WDGS and wheat straw. Further, the resulting mix after storage can be fed on the ground in range and pasture situations where cubes (cake) are normally fed on the ground. South Dakota State researchers (Kalscheur et al., 2002, 2003, 2004) have successfully ensiled WDGS in silo bags in combination with corn silage, soybean hulls, or wet beet pulp. Fermentation characteristics were excellent with several ratios of WDGS with the other products.

By-product Economics

The type of by-product, dietary inclusion level, moisture content, trucking costs, feeding costs, and price relationship between by-products and corn price affect cattle feeding profit or loss when using by-products. The Co-product Optimizer Decision Evaluator (Cattle CODE, at <http://beef.unl.edu>; Buckner et al., 2008a) is a model designed to evaluate these factors and estimate profit or loss from feeding by-products in feedlot diets.

Cattle CODE requires cattle inputs of feeder and finished body weight and their respective prices. DMI and feed conversion for cattle fed

a corn-based diet with no by-products are required inputs. Cattle processing and medical costs, death loss, yardage costs, and loan interest are also required. Feed ingredient prices, ingredient percent dry matter, and dietary inclusion level on a dry matter basis are needed for corn, by-products, roughages, and supplement. Inputs of semi-truck load size, cost/loaded mile, and miles hauled to the feedlot are needed for trucking costs.

With these inputs, the model predicts DMI and feed conversion for each by-product type inclusion based on equations from research trials. With predicted DMI and feed conversion, the model calculates ADG. Feeder and fat cattle body weights do not change in the model with inclusion of by-products. Therefore, days on feed are calculated based on ADG.

Yardage costs are divided into two parts. The model assumes one-third of yardage cost was for feeding costs while the other two-thirds was for non-feeding yardage costs. The feeding yardage cost component accounts for costs associated with feeding wetter diets due to wet by-product inclusions.

The model adds urea (and associated cost) to diets when supplemental protein is needed to obtain at least 13.5% dietary crude protein. The model calculates dietary dry matter content with the inputs of feed ingredient dry matter and percent inclusion, which is important for calculating feeding yardage costs. By-product hauling costs are calculated with load size, cost/loaded mile, and miles delivered to the feedlot.

A few by-product feeding scenarios were evaluated to illustrate how this model can calculate profit/loss with any given inputs. Assumptions for inputs included 740-pound feeder steer at breakeven price to cause the corn diet to have \$0 profit, 1,300-pound finished steer at \$90/cwt, 24 pounds DMI and 0.154 feed efficiency for cattle consuming a corn-based diet. Transportation cost was assumed to be \$3.90 per 25 tons of as-is by-product per loaded mile.

The distance between the ethanol plant and the feedlot affected cattle returns when feeding WDGS. Feeding WDGS (priced at 70% of \$5.50/bu corn price) increased returns quadratically, as WDGS inclusion levels increased up to 50% of the diet dry matter compared to feeding corn

alone (Figure 2.5). If the feedlot was at the ethanol plant, the optimum WDGS inclusion level was 50% of diet dry matter and returns were \$109 more per finished steer compared to feeding corn. As the distance from the ethanol plant to the feedlot increased from 0 to 100 miles, the returns decreased for feeding WDGS when compared to corn alone. The optimum inclusion of WDGS also decreased as distance from the ethanol plant to the feedlot increased. The optimum inclusion of WDGS is 40%–50% if the feedlot is 100 miles away from the plant. The distance from the ethanol plant to the feedlot has an increased impact on economic returns as dietary inclusion level increases.

With a constant corn price (\$5.50/bu) and distance (60 miles), economic returns were sensitive to the price of WDGS relative to corn. With WDGS priced at 90% of the corn price, optimum inclusion of WDGS was 30% to 40% (Figure 2.6). This returned \$45/steer. The optimum inclusion of WDGS was 40% to 50% of diet dry matter when WDGS were priced at 75% of the price of corn, and returns were \$75/steer. When pricing WDGS at 60% of corn price, the optimum inclusion level

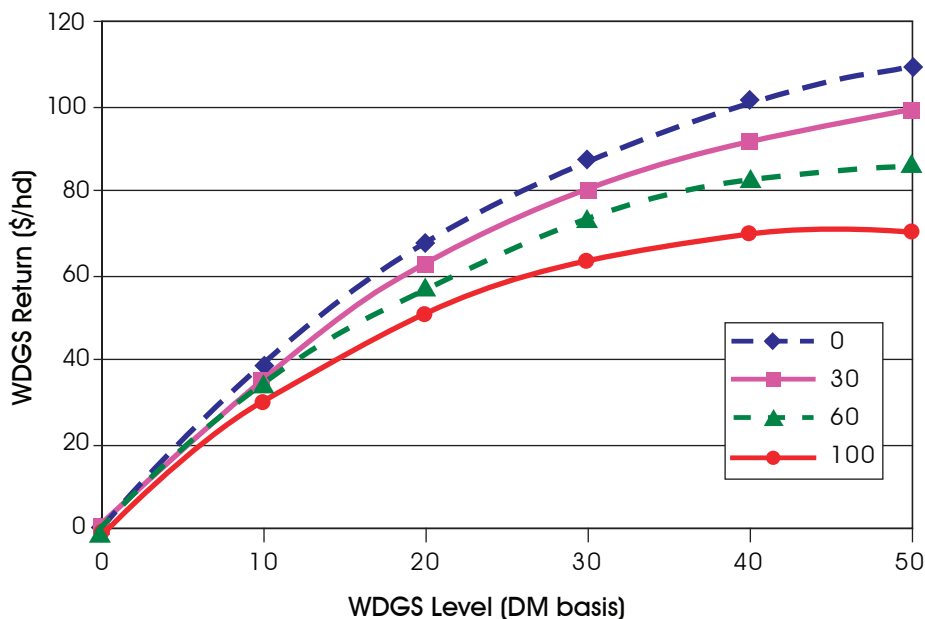


Figure 2.5. Economic returns from feeding wet distillers grains with solubles at 70% the price of corn (\$5.50/bu corn) at 0, 30, 60, and 100 miles from the ethanol plant

increased to 50% diet dry matter and returned \$105/steer. Pricing WDGS at a lower cost relative to corn improves economic returns as inclusion of WDGS increases.

Corn prices of \$4.50, \$5.50, \$6.50, and \$7.50 were evaluated for WDGS priced at 70% of the price of corn, and with a feedlot that is 60 miles from the ethanol plant. Returns to WDGS feeding increased quadratically as the level of WDGS inclusion increased for all corn prices (Figure 2.7). However, as the corn price increased, the returns to feeding WDGS increased. In addition, as the corn price increased, the optimum inclusion of WDGS increased, from 40% to 50% of diet dry matter for \$4.50 corn to 50% of diet dry matter at \$5.50 to \$7.50 corn.

We determined the effect on cattle profitability of corn prices at \$3.50, \$4.50, or \$5.50 per bushel with DDGS priced at 82% of the corn price, and with a constant 60-mile hauling distance for DDGS. Feeding DDGS resulted in a quadratic improvement in cattle profitability as the

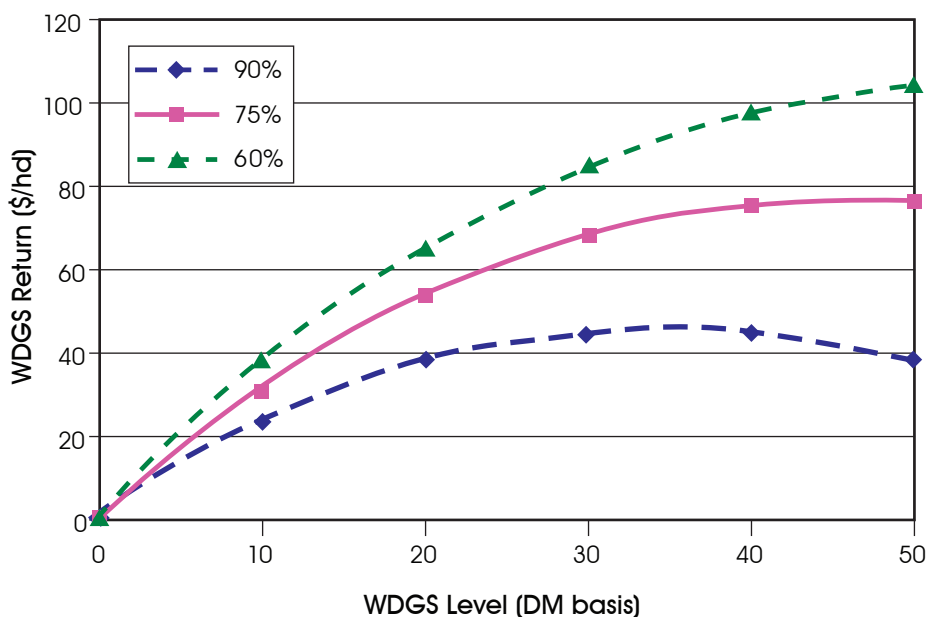


Figure 2.6. Economic returns from feeding wet distillers grains with solubles (WDGS) with \$5.50/bu corn at 60 miles from the ethanol plant with WDGS at 90%, 75%, and 60% the price of corn (dry matter basis)

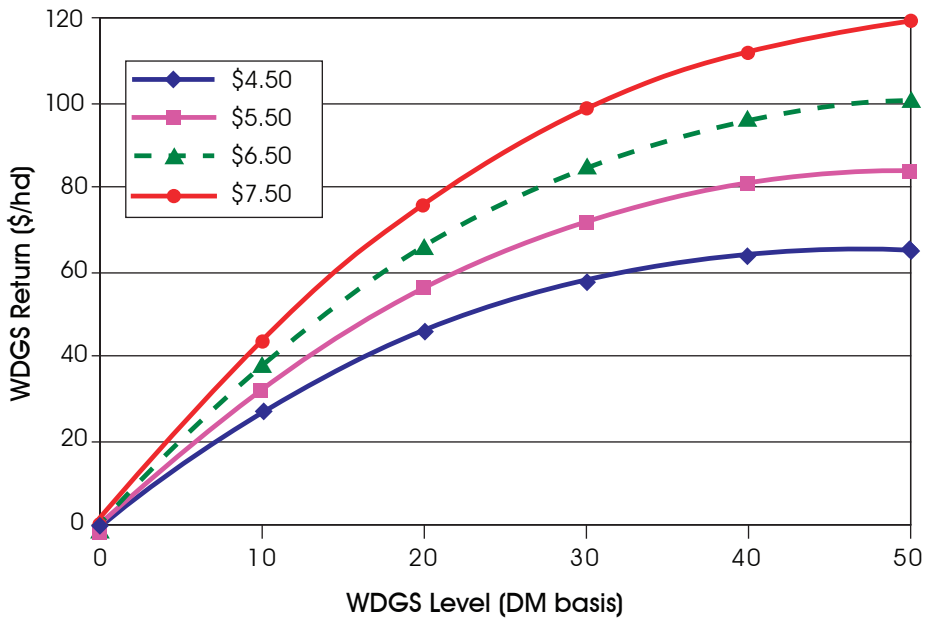


Figure 2.7. Economic returns from feeding wet distillers grains with solubles (WDGS) at 60 miles from the ethanol plant with WDGS priced at 70% the price of corn, when corn is priced at \$4.50, \$5.50, \$6.50, and \$7.50/bu

level of DDGS increased (Figure 2.8). As the corn price increased, the optimum DDGS inclusion level remained relatively constant at 20%–25% of diet dry matter. The DDGS increased returns by \$27 to \$40 per finished steer at each corn price. Increasing corn prices improved returns for feeding DDGS, and the most beneficial returns were observed at intermediate dietary inclusion levels of DDGS. Similar relationships were observed with feeding WDGS and increasing corn prices; that is, as the corn price increases, more profit results from greater inclusion of WDGS.

Based on these limited examples, feeding by-products increased cattle economic returns compared to feeding corn. However, returns were affected by the type of by-product used, inclusion level in the diet, distance from the ethanol plant, corn price, and by-product price relative to corn. This model should allow producers to use their own inputs and improve their decision-making ability about using by-products. The model can be downloaded at the University of Nebraska Beef Extension Web site (<http://beef.unl.edu> located under the “by-product feeds” tab).

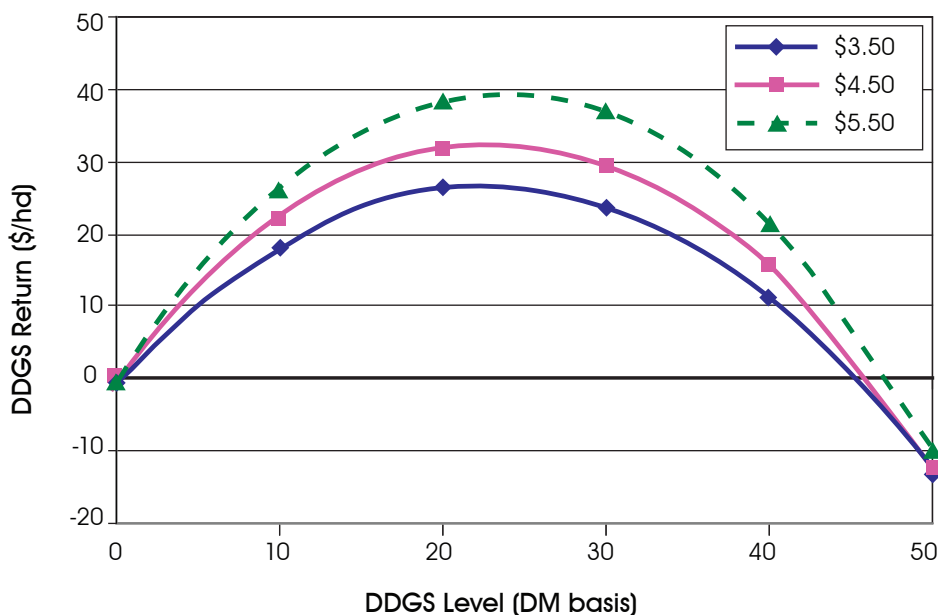


Figure 2.8. Economic returns from feeding distillers dried grain with solubles (DDGS) at 60 miles from the ethanol plant with DDGS priced at 82% the price of corn, when corn is priced at \$3.50, \$4.50, and \$5.50 per bushel

New Ethanol Industry By-products

The evolving ethanol industry is continually striving to maximize ethanol production efficiency. Changes associated with this progress will provide innovative new by-product feeds for producers to utilize that may be quite different nutritionally when fed to cattle. One example of a new by-product feed is Dakota Bran Cake. Bran cake is a distillers by-product feed produced as primarily corn bran plus distillers solubles produced from a prefractionation dry milling process. On a dry matter basis, bran cake contains less protein than WDGS or wet corn gluten feed, similar NDF to both feeds, and similar to slightly less fat content than WDGS. Bremer et al. (2006) evaluated Dakota Bran Cake in a finishing diet by comparing inclusion levels of 0%, 15%, 30%, and 45% of diet dry matter. Results indicated improved final body weight, ADG, DMI, and feed efficiency compared to feeding a blend of high-moisture and dry-rolled corn, suggesting this specific feed has 100%–108% of the feeding value of corn. Buckner et al. (2007) compared dried Dakota Bran

Cake to DDGS supplementation in growing calf diets. They fed each of the two products at 15% or 30% of the diet replacing a 70:30 blend of brome grass hay and alfalfa haylage (dry matter basis). Animal performance improved as the inclusion of the by-products increased. DDGS had improved performance compared to the dried Dakota Bran Cake at both inclusion levels. Dried Dakota Bran Cake had 84% of the feeding value of DDGS with growing steers. Previous research has shown DDGS to have about 127% of the feeding value of corn in forage-based diets. Therefore, dried Dakota Bran Cake appears to have an energy value approximately equal to 103% of corn.

Dakota Bran Cake is only one example of how new ethanol industry by-products will feed relative to traditional finishing rations. Each new by-product feed needs to be analyzed individually for correct feeding value. Changes to plant production goals and production efficiency have a significant impact on the feeding value of the by-products produced.

Conclusions

Distillers grains offer many feeding options to producers when included in feedlot and forage diets. These by-product feeds may effectively improve cattle performance and operation profitability. Distillers grains provide an excellent protein source for cattle, but as supplies increase, a greater amount is being used as an energy source, replacing grain (primarily corn) that is being used as a feedstock by ethanol plants. The feeding value of WDGS is greater than that of dry-rolled corn in beef finishing diets, and the feeding value is dependant upon the level of inclusion. Drying appears to reduce the feeding value of by-products when fed to feedlot cattle. The ability to keep cattle on feed and acidosis control are likely responsible for the higher apparent feeding values and may be the primary advantages of using WDGS in feedlot diets. Understanding and managing variations in fat and sulfur levels in distillers grains products may help optimize distillers grains inclusion in feedlot diets. There appears to be an interaction between the level of distillers grains in the diet and the type of corn processing used. As with many aspects of cattle nutrition, it is difficult to explain all of the interacting factors of distillers grains inclusion in diets. This provides a great opportunity for researchers and practicing nutritionists. The quality and quantity of roughages may be minimized in finishing diets

containing by-products. In the future, with a greater supply of by-products, feeding combinations of WDGS and wet corn gluten feed may be advantageous. The high undegradable intake protein value of distillers grains makes the by-products excellent protein sources for young, rapidly growing cattle and lactating cows. Alternate-day (or three days per week) feeding appears to be feasible, and DGS may have an advantage over grains, non-protein nitrogen sources, and more degradable protein sources in alternative-day feeding systems. Innovative ways of storing wet products offer opportunities for smaller producers to capture the value of by-product feeds. It also appears that new by-products will be available in the future as the processes of making ethanol and other products from corn evolve. These “new” feeds should be evaluated with performance data to determine their respective feeding values.

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